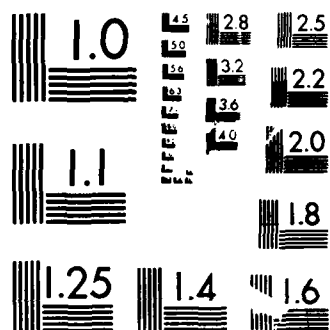MICROCOPY RESOLUTION TEST CHART

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A COMPARISON OF DIODE-LASER-DOPPLER
VELOCIMETER AND MEDIUM RESOLUTION
TURBULENCE CLUSTER MEASUREMENTS IN
MIZEX 84

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turbulence, diode-laser-Doppler velocimeter, ocean boundary layer, marginal ice zone, MIZEX, turbulent spectra, coherency

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
During the MIZEX 84 Experiment two prototype Diode-Laser-Doppler Velocimeters were tested in the oceanic boundary layer under a drifting ice floe. Part of the testing included a comparison of turbulent flow measured with the DLDV instruments and with a so-called Medium Resolution Cluster of small partially ducted rotors mounted along orthogonal axes, used in a separate boundary-layer experiment. This report presents data

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from 15 runs in which the two systems, suspended on the same
inverted mast but separated vertically by about half a meter,
measured the flow simultaneously. One-second averages of the
DLDV and MRC output are presented, along with statistics of flow
measured by each system, direct comparison of the horizontal and
45-degree components, and autospectra and squared coherency
calculated from each of 12 fourteen-minute runs. Overall, flow
measurements made with the DLDV instruments compare favorably
with those of the MRC.

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1.   Introduction

During the MIZEX 84 drift experiment deployed from the research vessel POLAR QUEEN in the Greenland Sea, prototype Diode-Laser-Doppler Velocimeters developed by Flow Industries, Kent, WA, were tested under field conditions by measuring the turbulent flow under drifting sea ice. Schedvin and Liu (1984) present a comprehensive description of the DLDV instrument, which works by measuring the Doppler shift of coherent light scattered from microscopic particles in a small fluid volume, and hence the near instantaneous fluid velocity. Laser-Doppler velocimetry is widely used for laboratory studies of turbulence, where gas lasers provide the light source, but has seen only limited application in field studies because until now the apparatus has been bulky and difficult to submerge in situ. The Flow Industries instrument obviates a number of these problems, and is theoretically capable of measuring to wave numbers well into the dissipation range of the turbulent spectrum of the oceanic boundary layer.

The field testing was done in conjunction with a boundary-layer turbulence study carried out by McPhee Research Company, Yakima, WA, using clusters of small mechanical rotors mounted along orthogonal axes in combination with fast response temperature and conductivity probes. The experiment, cluster description and calibration data are described by McPhee (1984, 1985). With proper orientation, the clusters are capable of measuring flow features with minimum length scales on the order of 20 cm (see, e.g, Smith, 1978). Since the energy-containing part of the turbulent spectrum in the near-ice boundary layer is typically concentrated at larger wavelengths, the clusters are capable of measuring turbulent stress. In this report we refer to the instrument grouping as a Medium Resolution Cluster (MRC). In MIZEX 84, six clusters were deployed at various depths, with digital data recorded from each of 30 channels at rates up to 6 per second.

2.   Simultaneous DLDV-MRC Data

During the MIZEX DLDV field tests, data were recorded by the MRC computer using a special hardware/software mode that allowed two channels of DLDV data to be sampled 48 times per second, and 5 channels of MRC (1 cluster) to be sampled at 24 per sec. The two DLDV sensors were mounted on a rigid frame suspended through a hole in the ice, oriented so that one measured horizontal flow in the direction of frame alignment, and the other measured flow at a 45 degree angle in the vertical plane of the horizontal component. In order to

1

compare the two sytems, one MRC was mounted 35 cm above the DLDV mounting (which separated the horizontal measurement frames by about 50 cm). Figure 1 shows schematically the deployment configuration, and a plan view of the MRC.

Fifteen runs with simultaneous recording of DLDV and MRC data were made from 15-17 July 1984 (Julian days 197-199). Each run lasted 14 minutes. Table 1 lists the runs, the combination of DLDV sensor and signal processing electronics used during the run, and the calibration constants used for calculating flow velocity (courtesy of J. Kolle, personal communication).

			Macrodyne (Channel 0)			TSI (Channel 1)			
Run	Date	Time	Sensor	Angle	Cal.	Sensor	Angle	Cal.	
197.E	7/15	15:26	LDL	Hor.	7156	---------------------			
197.F	7/15	15:46	Hitachi	45	7606	---------------------			
197.G	7/15	16:14	LDL	Hor.	7156	Hitachi	45	0.119	
198.A	7/16	20:10	Hitachi	45	7606	---------------------			*
198.B	7/16	20:34	LDL	Hor.	7159	---------------------			
198.C	7/16	22:23	Hitachi	45	7606	---------------------			*
198.D	7/16	22:45	LDL	Hor.	7159	---------------------			*
199.A	7/17	11:46	LDL	Hor.	7159	---------------------			
199.B	7/17	12:07	Hitachi	45	7606	---------------------			
199.C	7/17	15:37	Hitachi	45	7606	Hitachi	45	0.119	**
199.D	7/17	16:00	LDL	Hor.	7156	Hitachi	45	0.119	
199.E	7/17	17:12	LDL	Hor.	7156	Hitachi	45	0.119	
199.F	7/17	17:33	Hitachi	45	7606	Hitachi	45	0.119	
199.G	7/17	20:53	Hitachi	45	7606	Hitachi	45	0.119	
199.H	7/17	21:14	LDL	Hor.	7156	Hitachi	45	0.119	

Table 1. All runs for which MRC and DLDV were recorded simultaneously. 'Cal.' refers to the velocity calibrations. Runs marked with asterisk were not considered because of low currents or spikiness in the data. Channel 1 (TSI) was connected several minutes into Run 199.C (**); however, its data were ignored.

The mechanical characteristics of the MRC velocity sensors are such that a rotor completes one revolution (hence triggering the Hall Effect magnetic pulse generating electronics) in 1 second if the mean flow velocity is roughly 8 cm/s. Since no information is gained by sampling faster than the minimum revolution time, and typical minimum (component) velocities were of the order 7-8 cm/s, an averaging time of one second was chosen for the intercomparison.

Data were averaged in 1-sec bins for all 5 velocity sensors for each 14 minute run listed in Table 1. In the averaging process used to obtain the 1-second samples, some rudimentary editing was done by eliminating all samples for which the velocity was outside the limits 3 to 30 cm/s. Runs 198.A, 198.C, and 198.D were eliminated from further analysis because of spikiness in the DLDV signal and threshold sticking problems with the MRC, leaving 12 runs for direct comparison. Table 1 shows that four different combinations of laser sensor and processing electronics are represented by the 12 runs. They are:

Group 1: LDL sensor mounted in the horizontal direction feeding to the Macrodyne deck unit (Channel 0); Hitachi sensor mounted at 45 deg feeding to the TSI deck unit (Channel 1). Runs 197.G, 199.D, 199.E, 199.H.

Group 2: LDL sensor horizontal, Macrodyne deck unit (Channel 0); one channel only. Runs 197.E, 198.B, 199.A.

Group 3: Hitachi sensor at 45 deg, Macrodyne deck unit (Channel 0); one channel only. Runs 197.F, 199.B, and 199.C.

Group 4: Hitachi sensor at 45 deg, feeding to both deck units (Channels 0 and 1). Runs 199.F and 199.G.

3. Velocity Comparison

From the geometry of the cluster configuration diagrammed in Figure 1b, the following transformation provides the horizontal (UH) and 45-degree (U45) flow components in terms of the three MRC components:

$$UH = u_2 \,/\!\sqrt{2} + (u_1 + u_3)/2$$

$$U45 = UH/\sqrt{2} + (u_3 - u_1)/2$$

Table 2a lists the mean and sample variance of all the 1-second samples for each DLDV channel and the corresponding derived MRC components for each run in Group 1. Table 2b lists the sample correlations between the laser sampled velocities and velocities measured with the MRC half a meter above (first two columns), between the two laser channels (third column), and between the MRC components (fourth column).

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Run	LDL-Ch0		MRC UH		Hit-Ch1		MRC U45	
	Mean	Var	Mean	Var	Mean	Var	Mean	Var
197.G	12.53	4.04	12.06	4.10	9.23	1.34	8.44	2.79
199.D	15.20	0.86	15.08	1.27	11.31	0.37	10.76	1.17
199.E	14.43	5.54	13.74	6.11	10.48	1.70	9.79	3.46
199.H	15.04	0.61	15.17	0.50	9.93	0.23	10.39	0.39

(a)

Run	Correlations			
	Ch0/MRC UH	Ch1/MRC U45	Ch0/Ch1	MRC UH/U45
197.G	0.76	0.56	0.77	0.95
199.D	0.75	0.50	0.64	0.94
199.E	0.91	0.80	0.91	0.95
199.H	0.68	0.53	0.71	0.94

(b)

Table 2. (a) Mean and variance of velocity (cm/s) for runs in Group 1. (b) Correlation coefficients between time series.

Figures 2 through 5 show the actual data (1-s averages) and corresponding autospectra and squared coherency. Auto and cross-spectra were calculated by tapering the data (840 sec) with a split cosine bell applied to 42 sec at each end, extending the series to 1024 s with zeros, then smoothing the periodogram with three passes of a modified Daniell filter of half width 4 (Bloomfield, 1976). The dashed line in the squared coherency plots is the 95% confidence level for significant correlation.

Horizontal velocities measured by the different instruments about 0.5 m apart are typically coherent to about -0.75 on the log (frequency) axis where frequency is in rad/s. Using a mean velocity of about 0.15 m/s from Table 2, this implies that 'eddies' with horizontal length scales greater than about 5 m (periods of about 35 sec) are consistently recorded at both levels. This is at least an order of magnitude greater than the resolution limit of the MRC cluster, and also about 10 times the vertical separation. Lack of much significant coherence at higher frequencies may indicate either that the vertical extent of the turbulent disturbances is limited to 10% of their horizontal extent, or that instrument response differs. The gross statistics of the flow are remarkably similar for the horizontal components, which confirms that the turbulent kinetic energy is dominated by lower wavenumber turbulence, as is generally found.

Table 3 and Figures 5-7 cover the second group, which is the same as Group 1, except that the DLDV 45-deg component was not recorded.

Run	LDL-Ch0		MRC UH		Correlation	
	Mean	Var	Mean	Var	Ch0/MRC UH	MRC UH/U45
197.E	11.70	1.18	11.05	1.27	0.76	0.93
198.B	11.67	0.93	11.53	0.67	0.86	0.96
199.A	15.71	1.16	15.39	1.15	0.73	0.89

Table 3. Mean and variance of velocity (cm/s), and correlation coefficients for runs in Group 2 (LDL horizontal, through Macrodyne).

Table 4 and Figures 9-11 cover the single channel combination of the Hitachi sensor and Macrodyne deck unit, compared with the MRC 45 deg component.

Run	Hit-Ch0		MRC U45		Correlation	
	Mean	Var	Mean	Var	Ch0/MRC U45	MRC UH/U45
197.F	9.58	1.64	8.35	1.44	0.55	0.93
199.B	9.66	1.02	8.05	2.12	0.19	0.87
199.C	13.18	0.85	11.52	0.63	0.58	0.89

Table 4. Mean and variance of velocity (cm/s), and correlation coefficients for runs in Group 3 (Hitachi at 45 deg through Macrodyne).

Table 5 and Figures 12-13 show results for when the Hitachi sensor was processed through both Macrodyne and TSI deck units. Figure 14 shows the spectra for output from both channels with identical input, for each of the runs in this group.

Run	Hit-Ch0		Hit-Ch1		MRC-U45	
	Mean	Var	Mean	Var	Mean	Var
199.F	14.39	0.52	11.65	0.28	12.66	1.09
199.G	10.76	2.60	9.26	1.78	10.04	1.91

(a)

Run	Correlations		
	Ch0/MRC U45	Ch1/MRC U45	Ch0/Ch1
199.F	0.52	0.38	0.82
199.G	0.84	0.82	0.98

(b)

Table 5. (a) Mean and variance of velocity (cm/s) for runs in Group 4 (Hitachi at 45 deg, through both Macrodyne and TSI deck units). (b) Correlation coefficients between time series.

4. Conclusions

The overall impression gained from this comparison is that the two systems are capable of measuring turbulence at low wave numbers with similar response. The direct comparisons here suggest that the LDL-Macrodyne combination was successful at reproducing the 'energy-containing' part of the turbulent spectrum as measured by the MRC cluster; however, the 'blockiness' in the time series indicates problems at higher frequencies. The Hitachi-TSI combination appears to give better high frequency performance, but is noticeably deficient at low wavenumber. This situation appears to improve when the Hitachi is used in combination with the Macrodyne.

5. References

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Schedvin, J.C., and H.-T. Liu, 1984. The Development of a Diode Laser Doppler Velocimeter for Boundary Layer Measurements under Ice. Report TR-290/05-84, Flow Industries, Inc., Kent, Washington.

Smith, J.D. 1978. Measurement of Turbulence in Ocean Boundary Layers, Proceedings of a Working Conference on Current Measurement. Report DEL-SG-3-78, University of Delaware, 95-128.

6. Acknowledgment
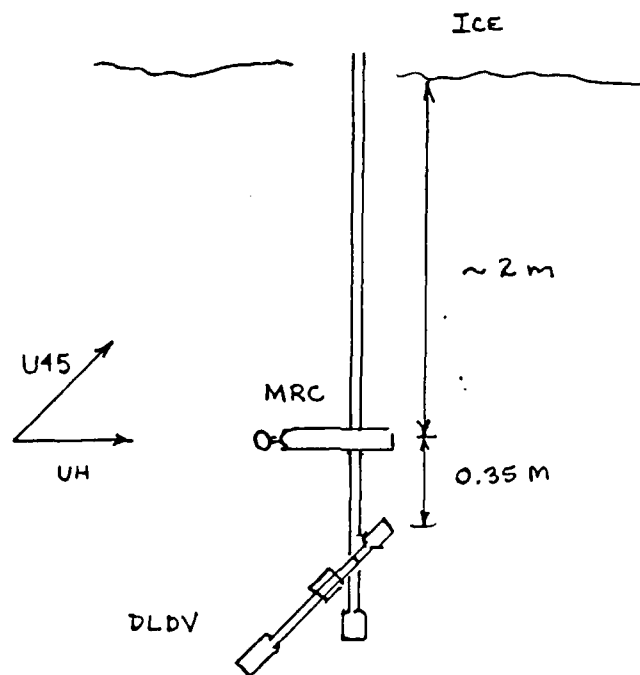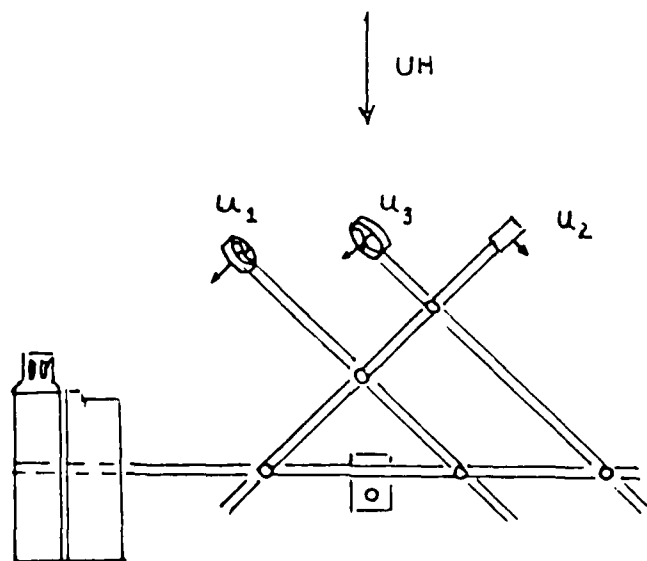
Figure 1. (a) Schematic of DLDV/MRC deployment. (b) Plan view of MRC showing UH direction.
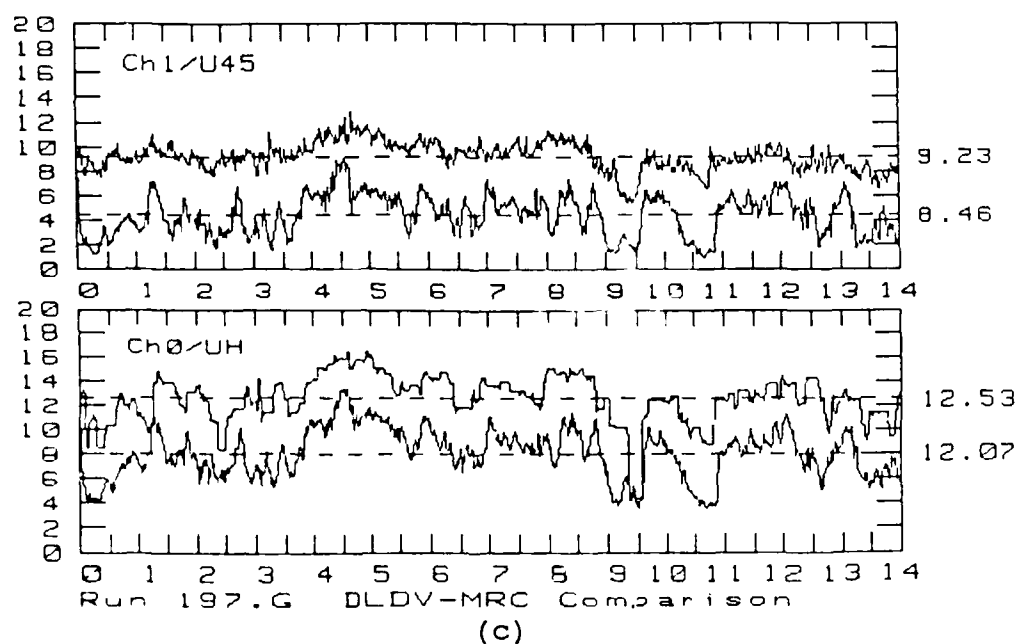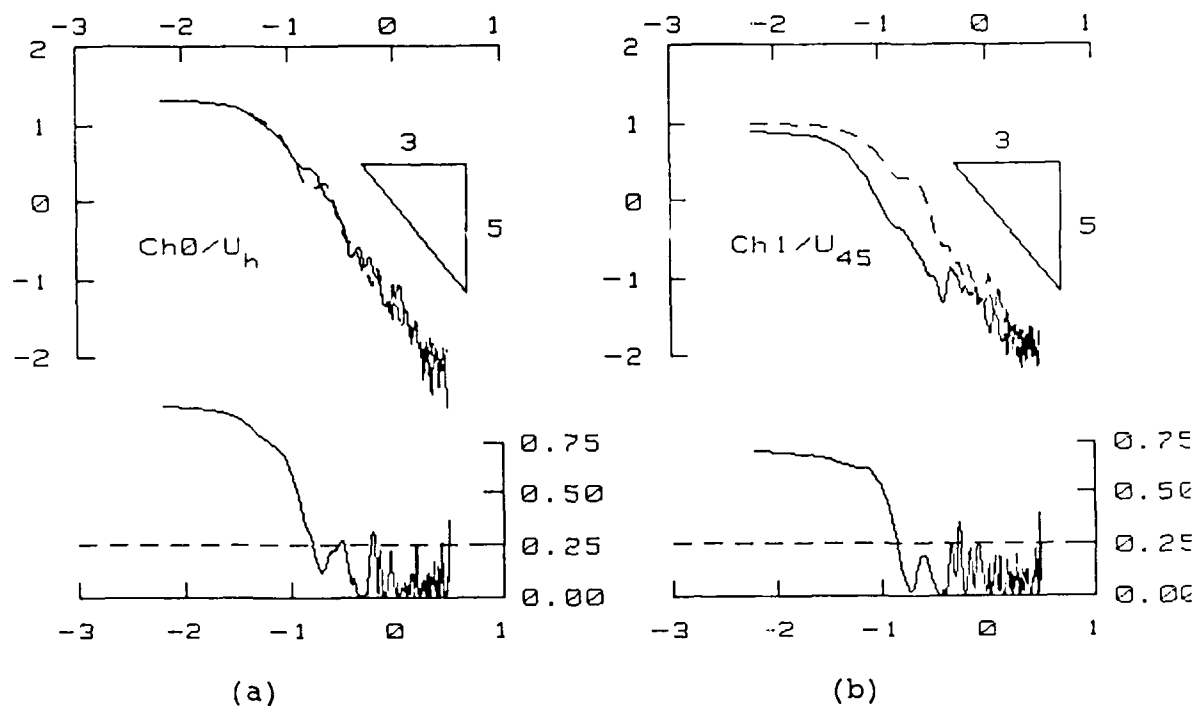
Figure 2. (a) Autospectra of LDL-Ch0 (solid) and MRC UH (dashed) components for Run 197.G. Abscissa units: log (frequency-rad/s); ordinate units $\log(cm^2/s)$. Lower trace is squared coherency. (b) Same as (a) except Hitachi-Ch1/U45. (c) Comparison of 1 second averages for 14 minute run in cm/s. MRC data displaced downward 4 cm/s; 14-min mean is displayed at right.
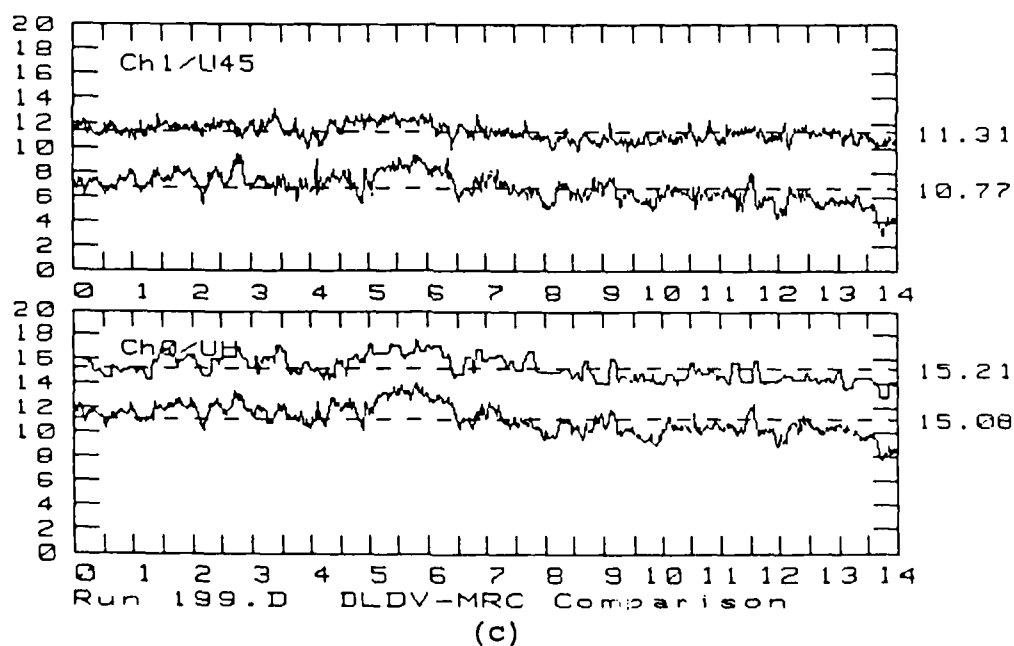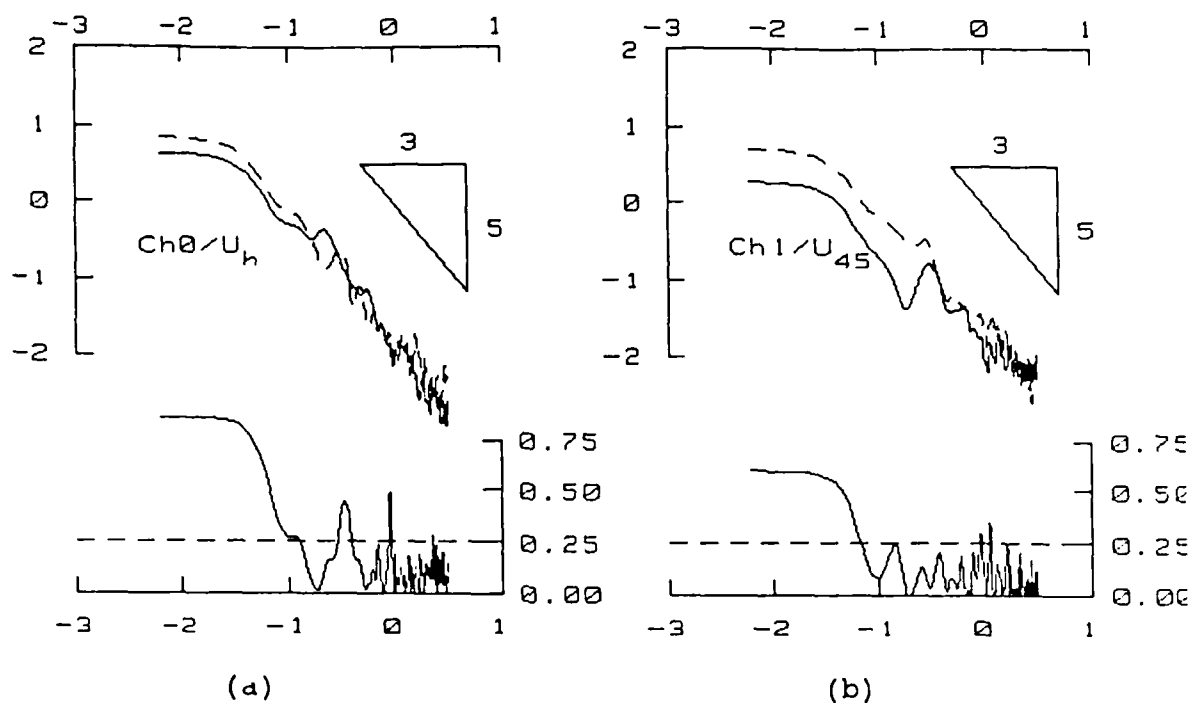
Figure 3. Same as Figure 2, except Run 199.D
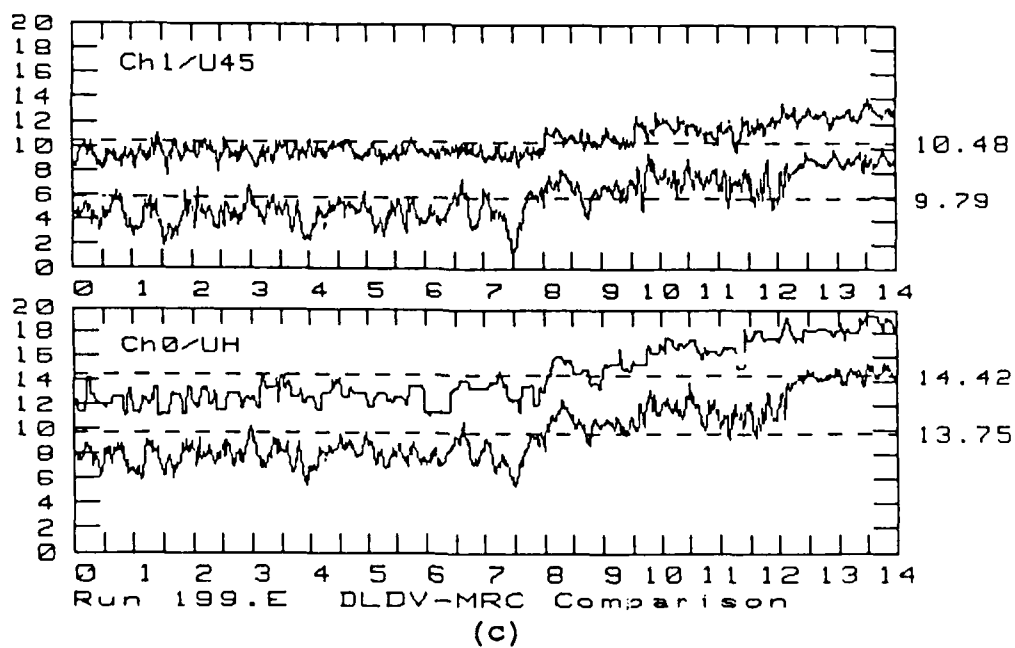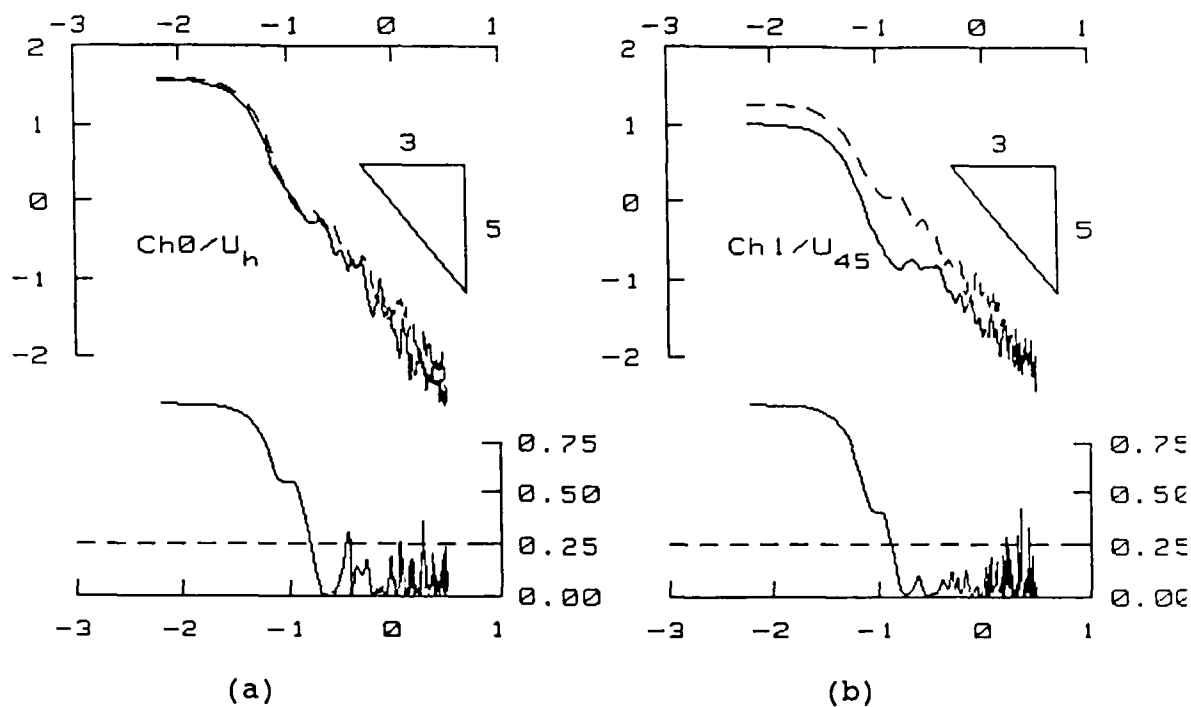
Figure 4. Same as Figure 1, except Run 199.E
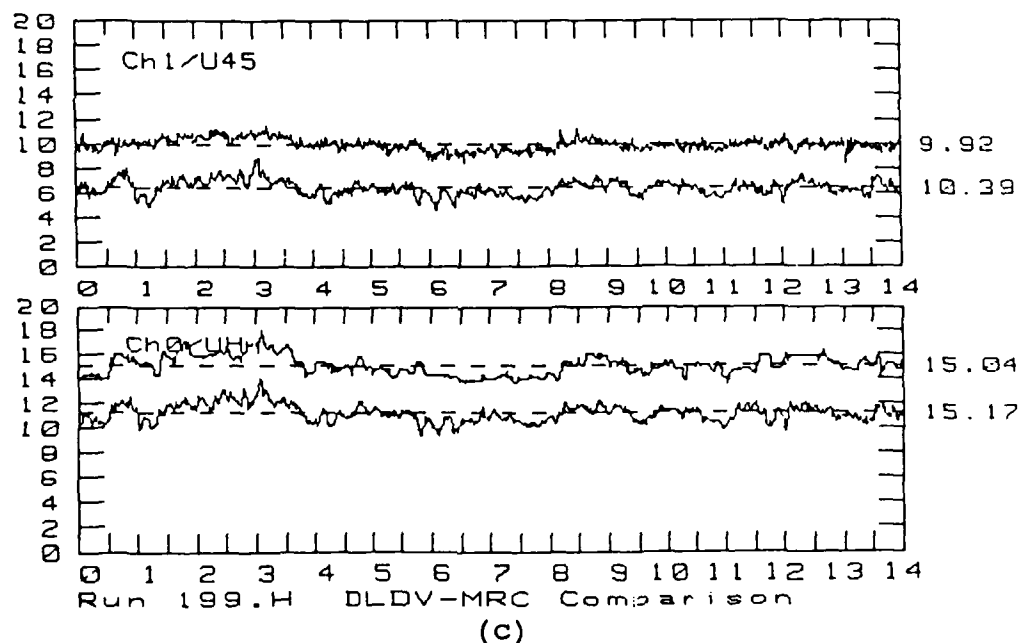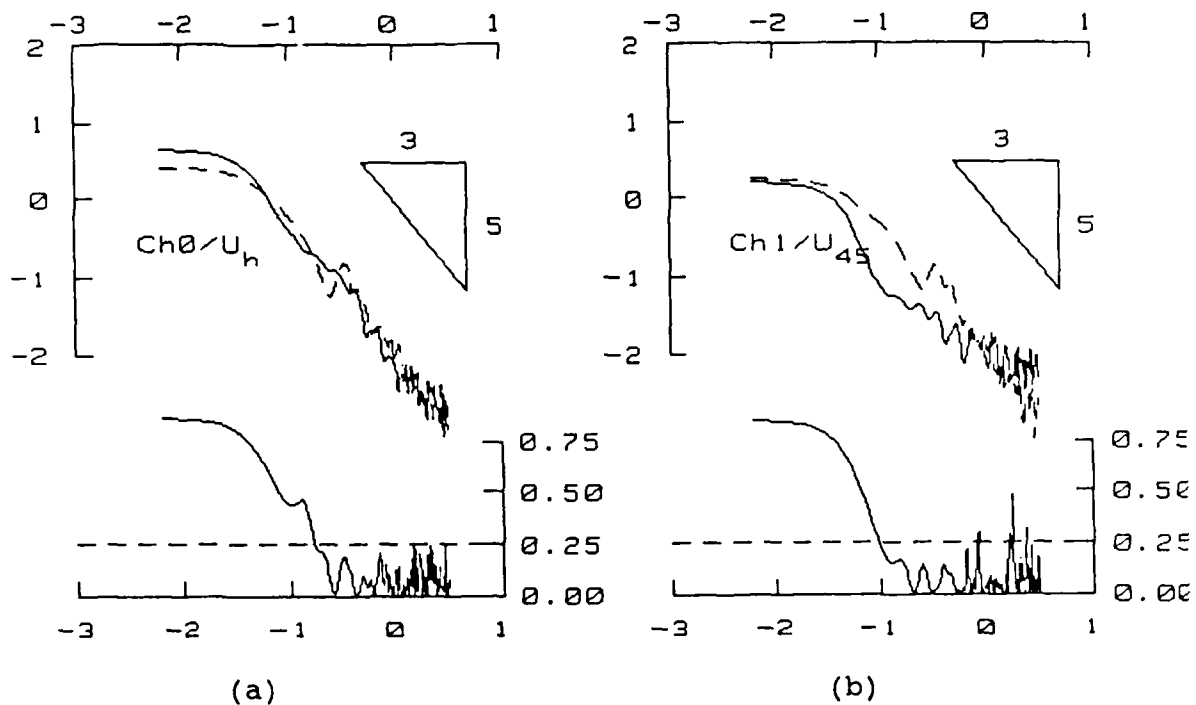
Figure 5.   Same as Figure 1, except Run 199.H
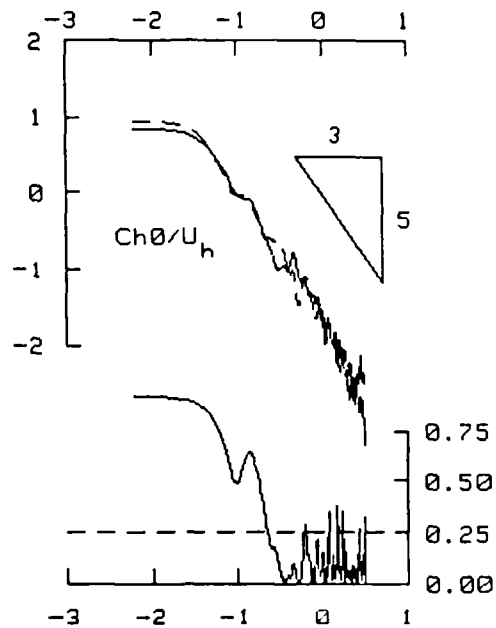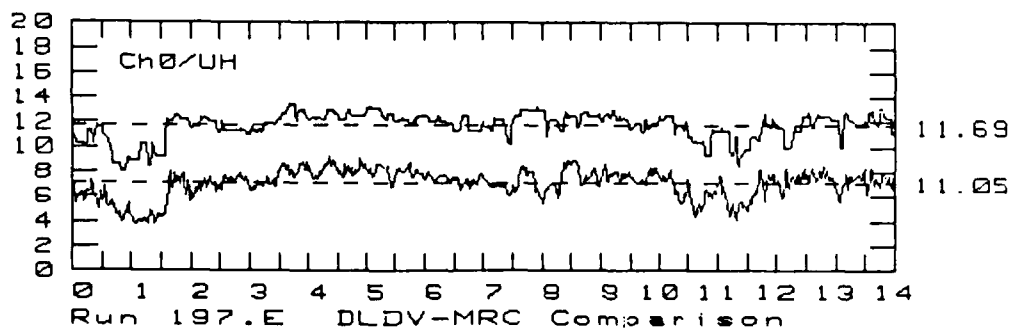
Figure 6. (a) Autospectra of LDL-Ch0 (solid) and MRC UH (dashed) components for Run 197.E. Lower trace is squared coherency. (b) Comparison of 1 sec averages for 14 minute run.
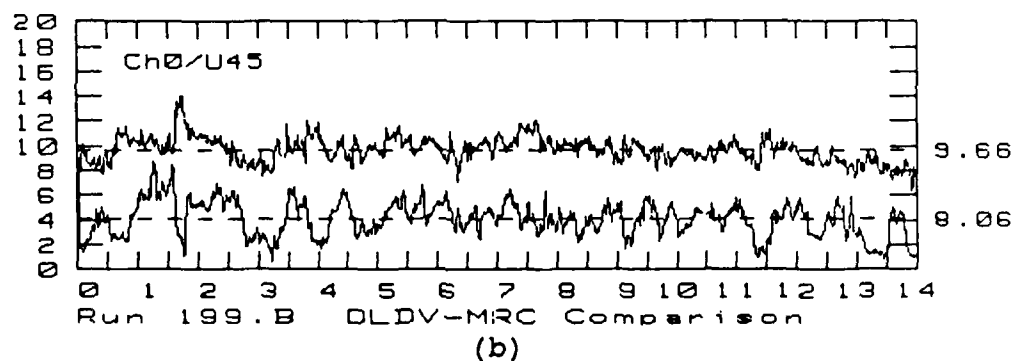
(a)

Run 198.B   DLDV-MRC Comparison
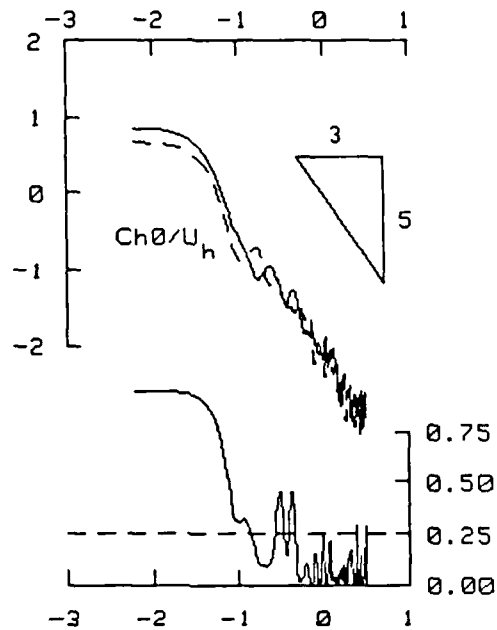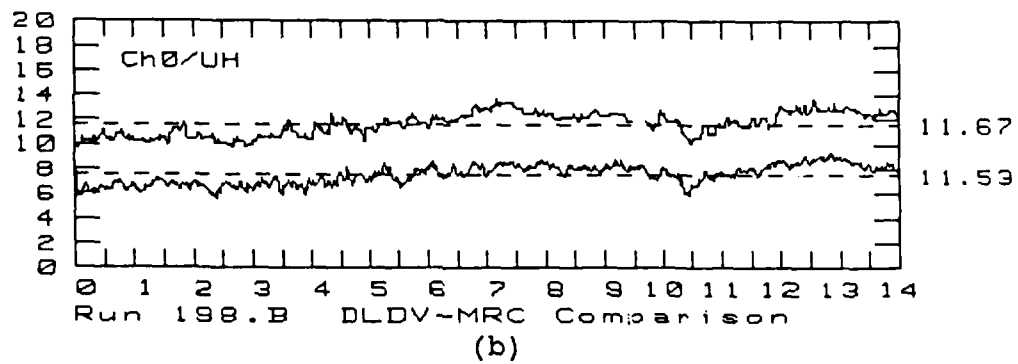
(b)

Figure 7.   Same as Figure 6, except Run 198.B
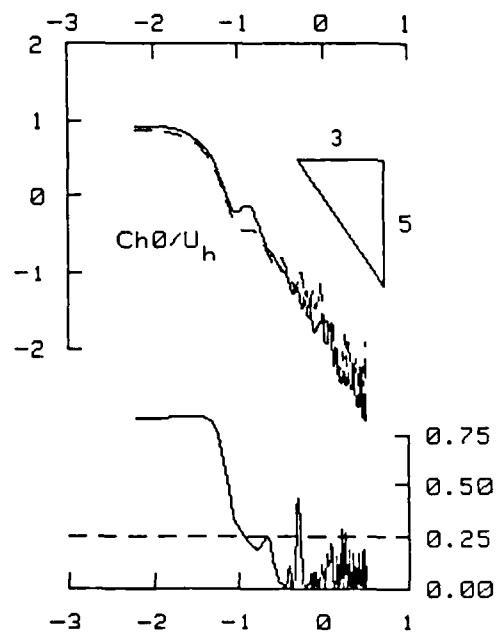
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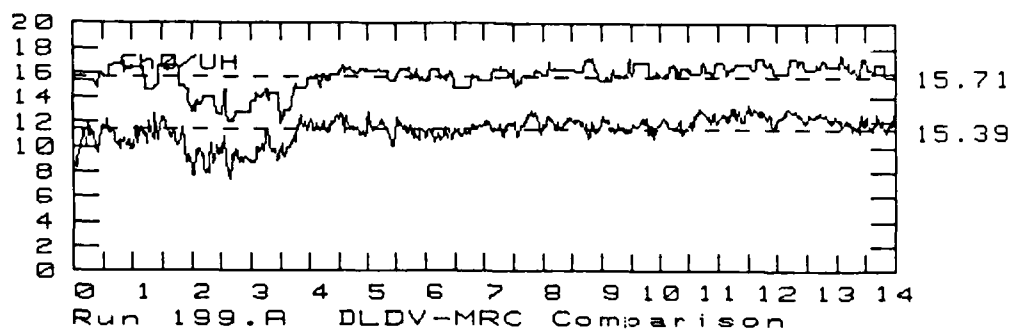
(b)

Figure 8.   Same as Figure 6, except Run 199.A

(a)

Run 197.F   DLDV-MRC Comparison
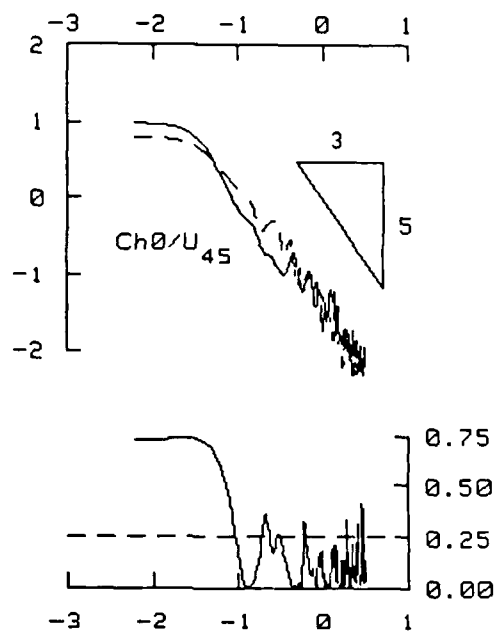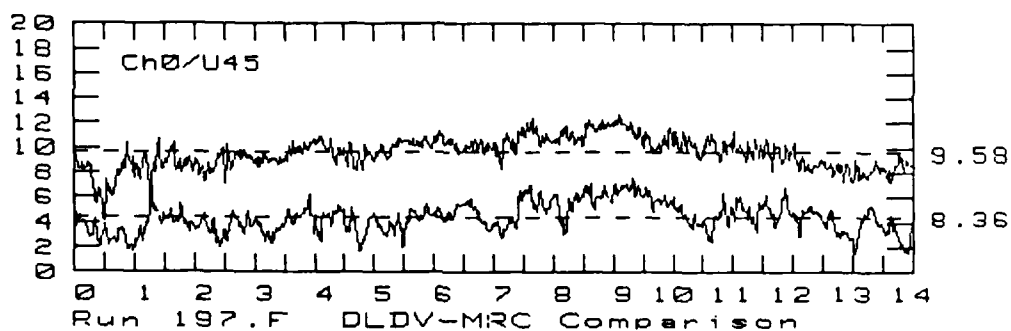
(b)

Figure 9.   (a) Autospectra of Hitachi-Ch0 (solid) and MRC U45 (dashed) components for Run 197.F.   Lower trace is squared coherency.   (b) Comparison of 1 sec averages for 14 minute run, MRC U45 offset 4 cm/s downward.

(a)

(b)
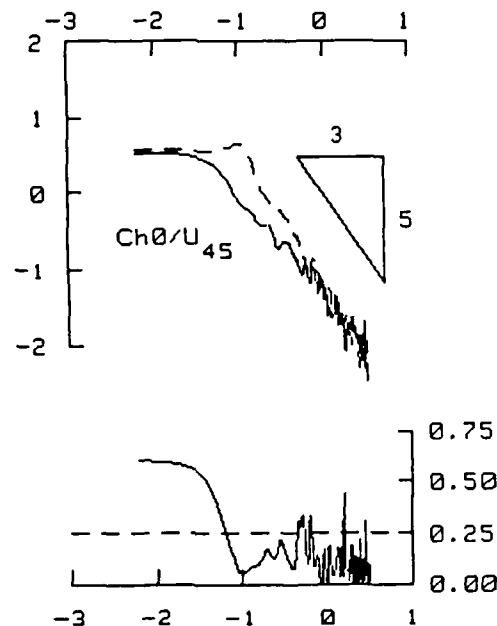
Figure 10.   Same as Figure 9, except Run 199.B.
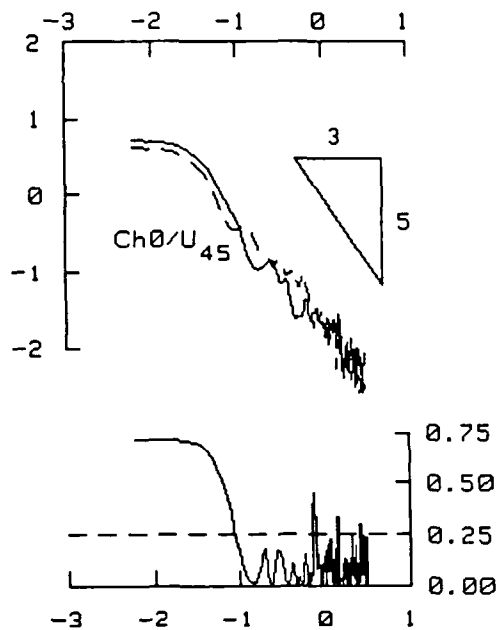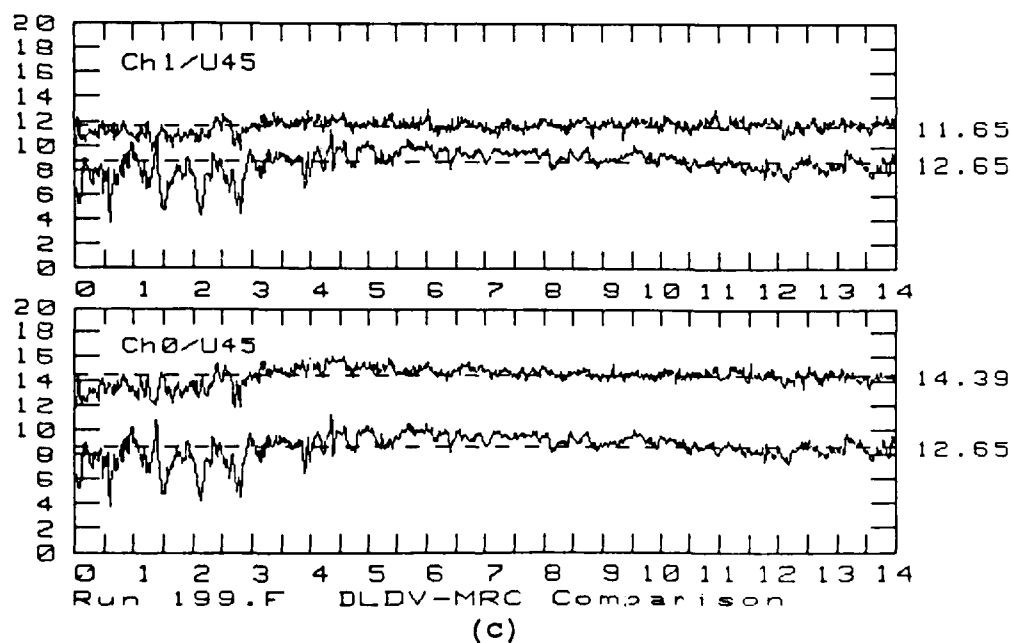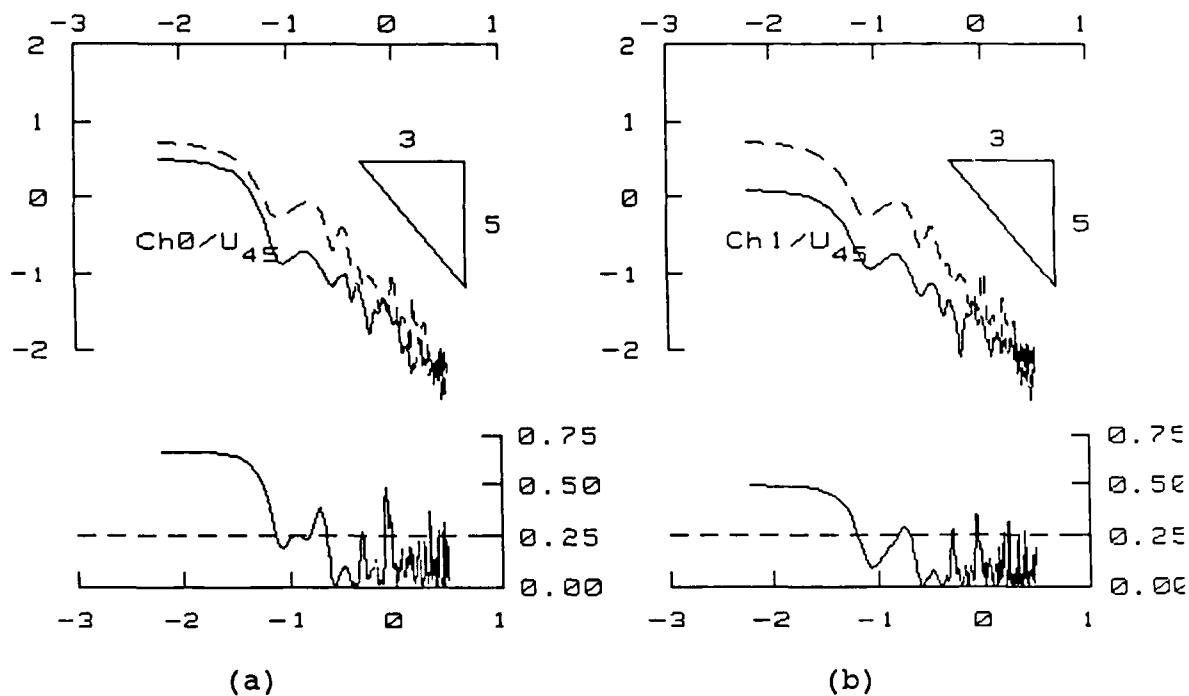
(a)
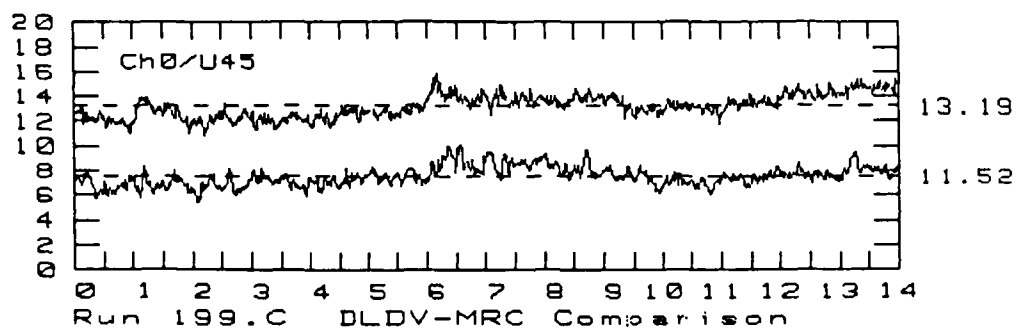
(b)

Figure 11. Same as Figure 9, except Run 199.C.

Figure 12. (a) Autospectra of Hitachi-Ch0 (solid) and MRC U45 (dashed) components for Run 199.F. (b) Same as (a) except Hitachi-Ch1/U45. (c) Comparison of each channel with MRC U45. Note that the DLDV input is identical for each channel.
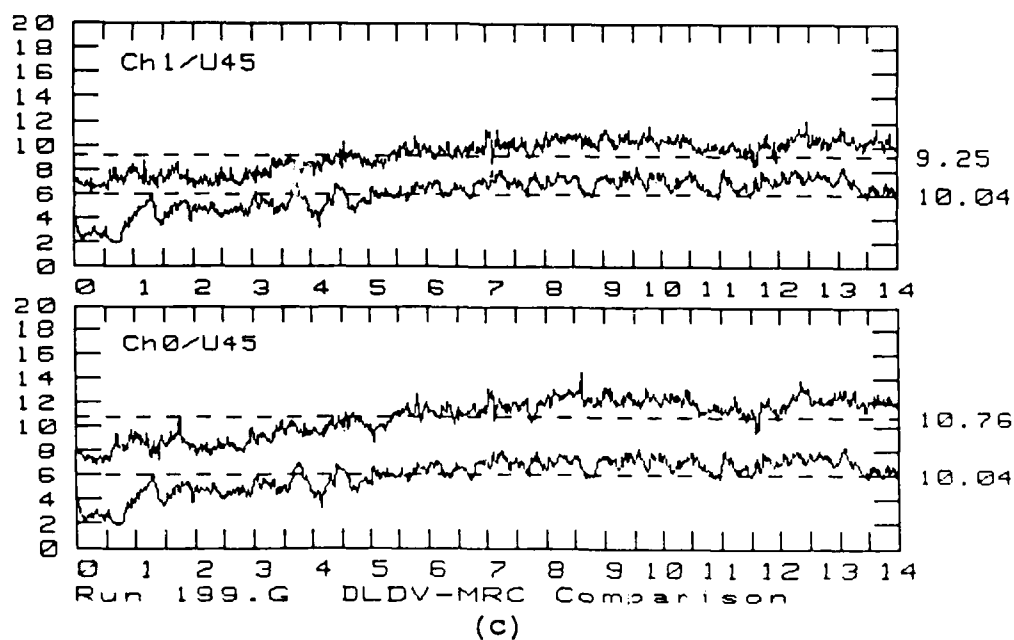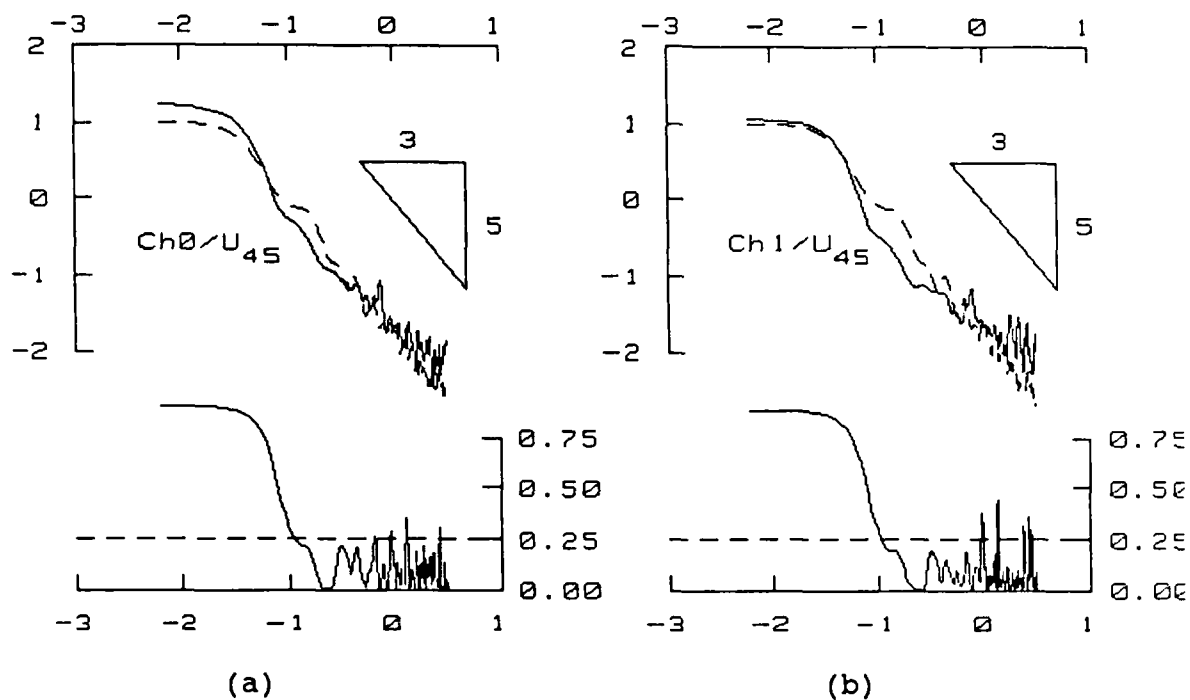
(a)

(b)

(c)

Run 199.G   DLDV-MRC Comparison

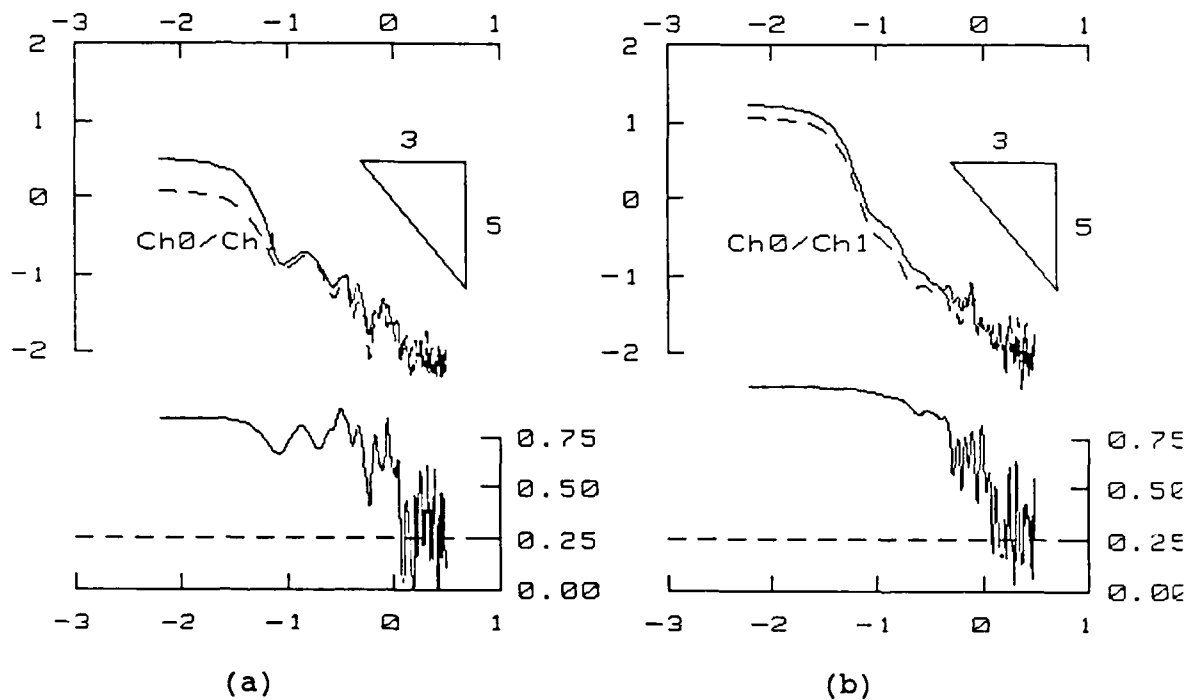Figure 13.   Same as Figure 12, except Run 199.G

Figure 14. Autospectra and squared coherency from two DLDV signal processing channels (Ch0: solid, Ch1: dashed) with input from same sensor (Hitachi). (a) Run 199.F; (b) Run 199.G.

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